Renewable and Sustainable Energy Reviews 28 (2013) 456–462

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Techno-economic analysis of stand-alone hybrid photovoltaic–diesel–battery systems for rural electrification in eastern part of Iran—A step toward sustainable rural development

Abolfazl Ghasemi [a,*], Arash Asrari [b], Mahdi Zarif [c], Sherif Abdelwahed [d]

[a] Khorasan Regional Electricity Company, Mashhad, Iran
[b] Department of Electrical Engineering & Computer Science, University of Central Florida, Orlando, FL, USA
[c] Department of Electrical Engineering, Mashhad Branch, Islamic Azad University, Iran
[d] Department of Electrical & Computer Engineering, Mississippi State University, Starkville, MS, USA

ARTICLE INFO

Article history:
Received 7 November 2012
Received in revised form
31 July 2013
Accepted 11 August 2013
Available online 31 August 2013

Keywords:
Photovoltaics (PV)
Hybrid renewable energy system
HOMER
Renewable fraction (RF)
Air pollutant emission

ABSTRACT

Almost all the villages consisting of more than 20 households in Iran have been grid-connected by 2010 according to the Forth Five-Year Economic Development Plan (2005–2010) of the Iranian government; however, there are many isolated communities with less than 20 households that are still in need of electrification. Currently, the sole technology that provides electric power to such communities is diesel generator, which does only cause environmental problems and human health concerns, but also rank high in maintenance and operational costs. Due to the recent increasing attention of Renewable Energy Organization in Iran (acronymed as SUNA based on its Persian name) to the application of renewable energies, this paper aims to analyze the techno-economic feasibility of stand-alone hybrid PV–diesel energy systems for electrification of remote rural areas in eastern part of Iran where 5 kW h/m^2 solar radiation per day is a common feature. Through simulations based on HOMER software, this study presents a comprehensive comparative analysis among potential configurations of a system best suited to meet the needs of isolated Iranian communities.

Contents

1. Introduction

Today it is estimated that approximately one third of the world' s population (i.e. around two billion people) has no access to electric power, potentially leading to recurrent cycles of poverty

* Corresponding author. Tel.: +98 9111 717439.
E-mail addresses: abolfazl.ghasemi@hotmail.com (A. Ghasemi), asrari@knights.ucf.edu (A. Asrari), zarif.mahdi.315@gmail.com (M. Zarif), sherif@ece.msstate.edu (S. Abdelwahed).

1364-0321/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2013.08.011

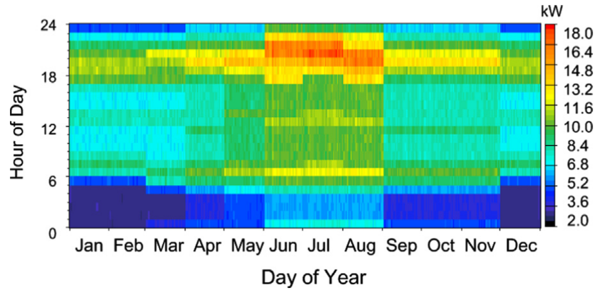

Fig. 1. DMap of the case study.

and privation [1]. One of the most promising solutions for electrification of such remote regions is installation of hybrid renewable energy systems in these areas, where the grid extension is costly and the cost of fuel is higher. Reliability improvement, cost reduction, efficiency enhancement and reduction of air pollutant emission are some of the advantages that can be gained by using hybrid renewable systems [2].

In Iran, although just 0.11% of produced electric power came from renewable energy sources (except hydro) in 2009, renewable energy technologies are getting more popular due to recent attention to high potentials of renewable energy in the country. According to the Fifth Five-Year Economic Development Plan (2010–2015) of the government, additional solar and wind generations will allow Iran to meet its target of increasing electric power generation from these two renewable sources to 5000 MW by the end of 2015. Despite the electrification of almost all Iranian villages with more than 20 households by 2010, there are numerous remote regions, with less than 20 households, that still suffer from lack of electric power. While utility extension to most of these areas is extremely uneconomic, some of them are blessed with abundant renewable sources such as solar energy. A clear example of these remote areas is a village named Khavar-E-Bala near Serayan town located in Khorasan-E-Jonoobi province of Iran. This village which is about 15 km far from the utility grid has no access to electric power although it enjoys an annual solar radiation of 5.1 kW h/m^2/d. Another remote area located in the same region (i.e. near Serayan) is Khoshnari village which is 24 km far from the utility power lines. To supply the essential loads of the village such as light, TV and fans, 14 units of 1.1 kW photovoltaic cells have recently been installed in this village of only 14 households. The cost of installation of this PV system was around $140,000. Studies show that if the village were electrified by the utility grid, the cost of grid extension would be about $500,000 [3]. The state-run electricity provider for the region, Khorasan Regional Electricity Company (KREC), has recently decided to install a 110 kW grid-connected photovoltaic array system to provide some part of its own electricity demand, 42 kW of which has already been operated [4].

Thanks to the implementation of the Iranian targeted subsidy plan, the use of solar energy is increasingly becoming more economically justifiable and, consequently, the investment return will improve and it is predicted that the solar power capacity will increase significantly in the near future [5].

This paper aims to analyze techno-economic feasibility of stand-alone hybrid PV–diesel energy system for electrification of remote villages. One such remote village, Khavar-E-Bala, located in the northeastern part of Iran, is adopted for this case study. In the next stage, battery banks will be included in the proposed hybrid system (i.e. PV–diesel system) to achieve the efficiency improvement of renewables as well as cost of energy (COE) reduction. In this study, a comprehensive comparative analysis among the potential configurations that can meet the needs of isolated Iranian communities is presented through simulations based on HOMER software [6] which is the most widely used optimization software for hybrid systems [7]. This software was used in a previous project to find the most economic and climate benign renewable hybrid system for electrifying the grid-connected village, Sheikh Abolhassan [8]. Another example for application of HOMER is [9] in which PV systems in off-grid locations have been shown to be economically viable.

2. HOMER software

HOMER, the micro-power optimization model, is a software package developed by National Renewable Energy Laboratory (NREL) in the USA. To assist in the design of both off-grid and grid-connected micro-power systems; and it facilitates the comparison of different distributed generation technologies across a variety of applications [10]. Using this software, different potential design options can be compared based on their technical and economic merits [11]. Simulation, optimization, and sensitivity analysis are three principal tasks that can be performed by HOMER. In the simulation process, HOMER performs energy balance calculations between demand and supply for each of the 8760 h in a year. Then, HOMER determines technical feasibility of a configuration and estimates the total cost of installing and operating the system over the lifetime of the project. In the optimization process, HOMER simulates all possible system configurations and displays a list of configurations satisfying the technical constraints which are sorted by their net present cost (NPC). HOMER uses the following equation to calculate the total net present cost [12]:

$$\mathrm{NPC} = \frac{C_{tot}^{ann}}{\mathrm{CRF}(i, R_P)} \tag{1}$$

where NPC is the total annualized cost ($), i refers to the annual real interest rate (%) and R_P stands for the project lifetime in years.

3. Background information

3.1. Electric load information

The case under study here, Khavar-E-Bala, is a remote rural area with no access to electricity, a condition that causes serious hardship to its 14 households to manage their daily affairs. Based on load profiles of similar villages in the area, the average annual electricity consumption of the village is estimated to be 200 kW h/d with a peak demand of 18 kW.

The DMap (Fig. 1) of the electric demand which is plotted based on day-to-day randomness (i.e. variation) of 2% and time-step-to-time-step randomness of 2% is used to show the fluctuation of electric power consumption in this village. The software is then ready to synthesize the load data to supply a unique load pattern for each day in a year [11]. As it can be seen from Fig. 1, the maximum consumption of electricity in this village on each day occurs at evening. Also, as it can be expected, the highest demanded loads, up to 18 kW, occur in summer and the lowest required electric power occurs in winter.

3.2. Solar radiation

Solar irradiation map for southeast countries of Asia, including Iran, is shown in Fig. 2. This figure represents the average annual energy per square meter that is available from solar source in different regions. The regions marked by yellow color in the map refer to areas enjoying high potentials of solar energy. As it is

clearly observable from the figure, most areas in Iran are in this region. So, they are suitable candidates for efficient application of solar energy.

The studied remote area is located at about 34°3′ North latitude and 58°30′ East longitude. The required solar data are obtained from the NASA surface meteorology and solar energy web site [14]. The profile of average annual solar radiation for this village is shown in Fig. 3. As is observed from the figure, solar radiation from May to August is more than that of other months. The scaled average annual of the daily solar radiation of the studied region is about 5.1 kW h/m^2/d.

Instead of solar radiation, the clearness index can also be used as the input for HOMER [11]. The clearness index is defined as the ratio of the solar radiation striking Earth′s surface to the solar radiation striking the top of the atmosphere, and varies from 0 to 1. Fig. 4 depicts the monthly clearness index for the case study location.

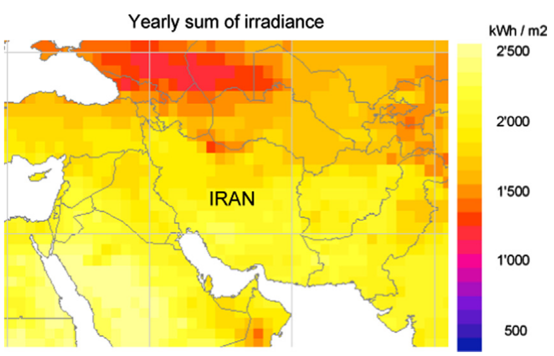

Fig. 2. Solar radiation map (kW h/m^2)[13].

4. Configurition of the proposed system

In a typical hybrid PV–diesel energy system, there are four main components (i.e. generators, PV modules, batteries and a converter) that need to be considered.

4.1. Diesel generator

The size of diesel generator, especially when generator and loads are connected to the same AC bus, should be accurately estimated to meet the peak demand of the electric power [15]. A 20 kW diesel generator is considered in this study to meet the peak demand that is18 kW. The excess 2 kW is considered as the spinning reserve that is 10% of annual peak load. It was assumed that the installation and replacement cost of the diesel generator would be $700/kW and $600/kW, respectively. Also, the operation and maintenance (O&M) cost of the generator was assumed to be $0.02/h; and its lifetime was considered 15,000 operating hours. At present, the diesel price in Iran is about $0.32/L [16].

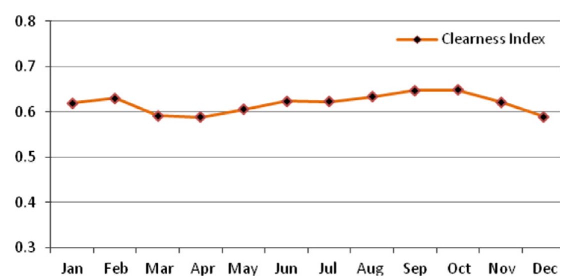

Fig. 4. Clearness index.

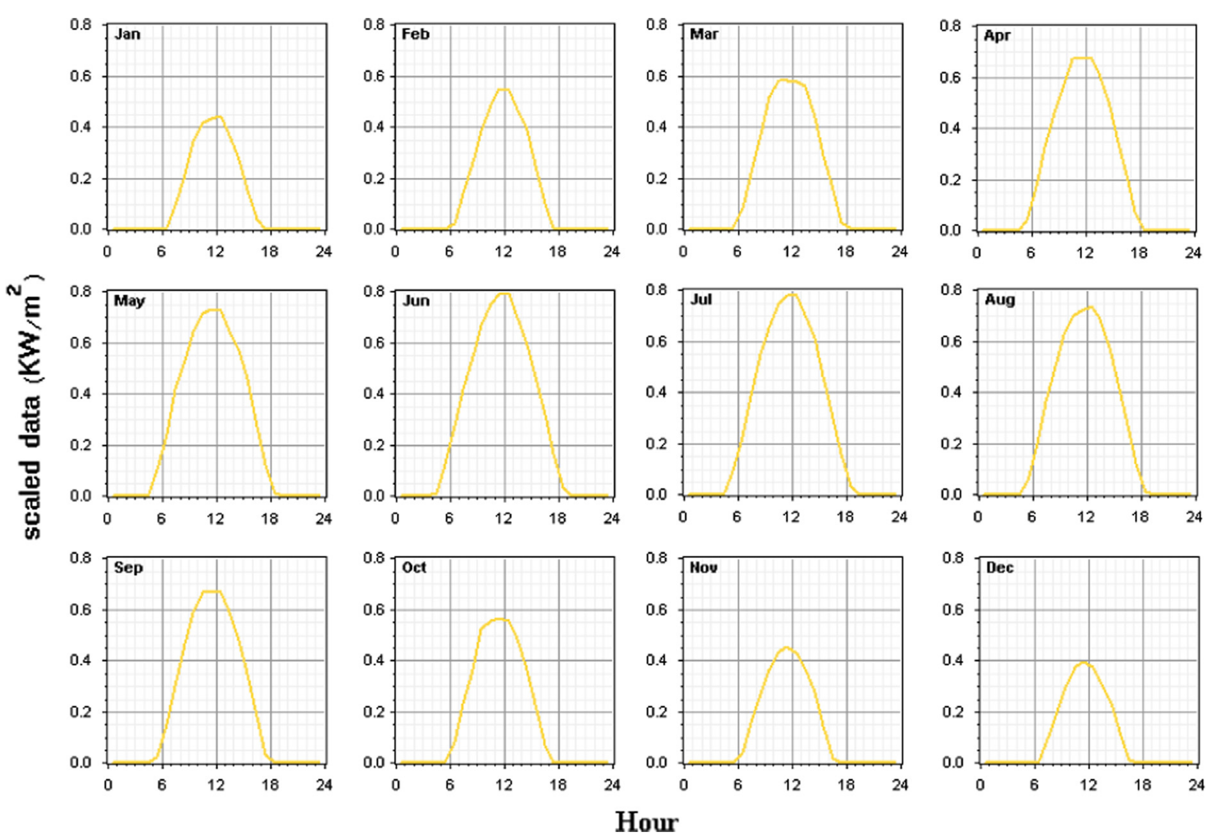

Fig. 3. Monthly average solar radiation profile for a year.

4.2. PV array

The PV array is an interconnection of PV modules producing direct-current (DC) from solar energy that is considered in this study as the base-load power source. Considering the market of renewable technologies in Iran, in this case, both installation and replacement costs for a 1 kW solar energy system are assumed $7000. The costs of operation and maintenance would be negligible. The life time for this PV array system is estimated to be 25 years. A de-rating factor of 0.9 is used to account for anything (e.g. dust on the panel) deteriorating efficiency of the PV.

The HOMER software calculates the produced power of the PV array using the following equation:

$$P_{PV} = f_{PV} Y_{PV} \frac{I_T}{I_S} \tag{2}$$

where, f_{pv} is the PV derating factor, Y_{pv} stands for the rated capacity of the PV array (kW), I_T refers to the global solar radiation (beam plus diffuse) incident on the surface of the PV array (kW/m^2), and I_S is the standard amount of radiation (1 kW/m^2).

Different sizes of PV panels (0, 10, 15, 20, and 30 kW) are included in the optimization analysis.

As the PV array generates electricity only during the day, there is no generated electric power from the PV panels at night; so the demand at night will be supplied either by battery or the generator. Therefore, the excess electricity produced by the PV system is suggested to be used to charge the battery bank.

4.3. Batteries

A bank of lead acid batteries is used in the proposed system. In the simulation process, it is assumed that the properties of the batteries are not affected by external factors (e.g. temperature) during their lifetime. The nominal voltage and capacity of the battery are 6 V and 360 A h, respectively. To keep the system more economically justifiable, the initial capital, replacement and O&M costs of each battery unit are assumed to be $300, $280 and $3/yr, respectively. Lifetime energy throughput of each battery is estimated at 1100 kW h. Different numbers of batteries (0, 10, 20, and 30) are included in the optimization analysis.

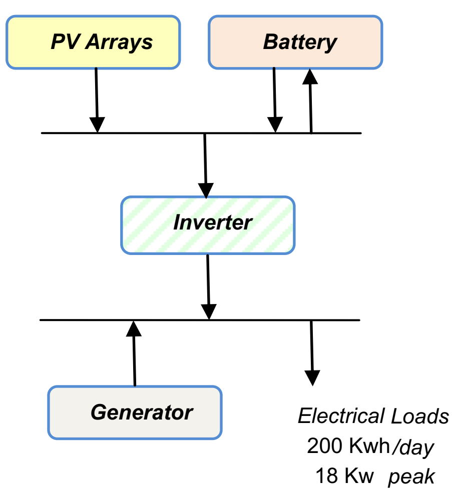

Fig. 5. Energy flow diagram of the system.

4.3.1. Battery-charging strategy

For charging the batteries, two different strategies could be provided by HOMER: *cycle-charging* and *load-following* [11]. In *cycle-charging* strategy, the generator operates in its nominal power and the batteries will be charged with surplus electricity. On the other hand, in *load-following* method, the batteries will be charged by renewable sources, and the generator produces only the amount of power that marginally meets the required load. In this study *Load-following* dispatch strategy is selected for battery charging. Therefore, in the proposed hybrid PV–diesel energy system, batteries will be charged only by PV panels.

4.4. Inverter

A power inverter is used to maintain the flow of energy from DC to AC buses [17]. Both the initial capital cost and replacement cost of the inverter used in this study are assumed to be $950/kW with the negligible O&M costs. The efficiency of the inverter is assumed to be 90% and its lifetime to be 15 years. The size of the proposed power inverter may range from 0 to 20 kW. The energy flow diagram of the proposed hybrid PV–diesel energy system is shown in Fig. 5.

5. Simulation results and discussion

A system simulation was performed based on an annual real interest rate of 10% and a project lifetime of 25 years. The categorized optimization results performed by HOMER for defined parameters (see Sections 3 and 4) are summarized in Table 1. As can be seen from Table 1, the stand-alone diesel system is the most economic system compared to other configurations. The total NPC for electricity supplying over project lifetime is $202,287. The low installation cost of this system plays an important role in its total NPC. Also, for this system the cost of energy (COE) is $0.304/kW h. Since no electric power is generated by renewable sources in this configuration, obviously the renewable fraction (RF) is equal to 0.

In this stand-alone system, the 20 kW diesel generator should be operated 8760 h to supply the electricity demand. As is shown in Table 2, the diesel generator uses 33,093 L of fuel to produce 76,309 kW h in a year. Consequently, this leads to the emission of 87,144 kg of carbon dioxide and 2349 kg of other pollutant gases in a year.

Table 1
Categorized optimization results.

System Components				PV (kW)	Gen (kW)	Inv (kW)	Battery no	Initial capital ($)	Operating cost ($/yr)	NPC ($)	COE ($/kWh)	RF
	✓			0	20	0	0	14,000	20,743	202,287	0.304	0.00
	✓	✓	✓	0	20	10	10	26,500	21,135	218,347	0.328	0.00
✓	✓	✓	✓	10	20	10	10	96,500	18,513	264,544	0.397	0.24
✓	✓	✓		10	20	0	0	93,500	20,266	277,456	0.417	0.22

5.1. Hybrid PV–diesel system without battery storage

In this subsection, the proposed system required to supply the load demand is analyzed based on a no battery scenario; that means the excess electricity produced by the PV system will not be stored; therefore, it is the diesel generator that solely supplies the demand at night. The optimization results for the hybrid PV–diesel system without battery storage calculated by HOMER and ranked according to total NPC are shown in Table 3. As can be seen from the last column of this table, the renewable fraction of the feasible systems supplying the electric demand varies from 22% to 51%. On one hand, the implementation of systems with a low renewable fraction may not lead to getting the advantages of hybrid renewable systems such as reduction in dependency on fossil fuels. On the other hand, high renewable fraction in an isolated hybrid system might result in difficulties in maintaining a stable voltage and frequency [18]. That is the reason why renewable sources are considered non-dispatchable. Therefore, as a trade-off process, the hybrid energy system, highlighted by red tick marks in Table 3, which consists of a 20 kW diesel generator, a 15 kW PV array and a 10 kW power inverter with renewable fraction of 30%, is selected as the most techno-economically justifiable configuration. The COE and NPC of the system are $0.464/kW h and $309,034 respectively.

The breakdown of cost for the proposed system and the share of each component in the total NPC are presented in Fig. 6. As is

Table 2
Diesel generator operation results and pollutant emissions for diesel-only system.

Quantity	Value	Units
Diesel generator		
Hours of operation	8,760	h/yr
Number of starts	1	starts/yr
Operational life	1.71	yr
Electrical production	76,309	kW h/yr
Mean electrical output	8.71	kW
Fuel consumption	33,093	L/yr
Pollutant		
Carbon dioxide	87,144	kg/yr
Carbon monoxide	215	kg/yr
Nitrogen oxides	1,919	kg/yr
Unburned hydrocarbons	23.8	kg/yr
Particulate matter	16.2	kg/yr
Sulfur dioxide	175	kg/yr

Table 4
System components operation results and pollutant emissions for PV–diesel system.

Quantity	Value	Units
PV array		
Rated capacity	15.0	kW
Mean output	79.1	kW h/d
Total production	28,879	kW h/yr
Hours of operation	4,380	h/yr
Diesel generator		
Hours of operation	8,620	h/yr
Number of starts	83	starts/yr
Operational life	1.74	yr
Electrical production	65,968	kW h/yr
Mean electrical output	7.6	kW
Fuel consumption	30,283	L/yr
System		
Excess electricity	20,334	kW h/yr
	21.4	%
Capacity shortage	0.0	%
Pollutant		
Carbon dioxide	79,745	kg/yr
Carbon monoxide	197	kg/yr
Nitrogen oxides	1,756	kg/yr
Unburned hydrocarbons	21.8	kg/yr
Particulate matter	14.8	kg/yr
Sulfur dioxide	160	kg/yr

Table 3
Optimization results for PV–diesel system.

Components			PV (kW)	Gen (kW)	Inv (kW)	Initial capital ($)	Operating cost ($/yr)	NPC ($)	COE ($/kWh)	RF
✓	✓	✓	10	20	10	93,500	20,266	277,456	0.417	0.22
✓	✓	✓	10	20	20	103,000	20,484	288,938	0.434	0.22
✓	✓	✓	**15**	**20**	**10**	**128,500**	**19,889**	**309,034**	**0.464**	**0.30**
✓	✓	✓	15	20	20	138,000	20,076	320,232	0.481	0.30
✓	✓	✓	20	20	10	163,500	18,856	334,660	0.503	0.38
✓	✓	✓	20	20	20	173,000	18,624	342,052	0.514	0.38
✓	✓	✓	30	20	20	243,000	16,395	391,814	0.588	0.51
✓	✓	✓	30	20	10	233,500	17,828	395,327	0.594	0.49

Component	Capital($)+Replacement($)	O&M($)	Fuel($)	Salvage($)	Total($)
PV	105,000	0	0	0	105,000
Diesel Gen	73,995	31,298	87,961	-701	192,552
Converter	11,774	0	0	-292	11,482
System	190,769	31,298	87,961	-994	309,034

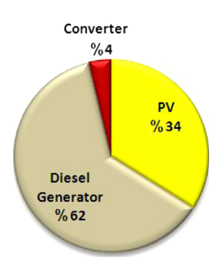

Fig. 6. Cost of PV–diesel power system.

Table 5
Optimization results for PV–diesel–battery system.

System Components				PV (kW)	Gen (kW)	Inv (kW)	Battery no	Initial capital ($)	Operating cost ($/yr)	NPC ($)	COE ($/kWh)	RF
✓	✓	✓	✓	10	20	10	10	96,500	18,513	264,544	0.397	0.24
✓	✓	✓	✓	10	20	20	30	112,000	18,014	275,518	0.414	0.24
✓	✓	✓	✓	**15**	**20**	**20**	**10**	**141,000**	**16,009**	**286,315**	**0.430**	**0.35**
✓	✓	✓	✓	15	20	20	20	144,000	15,954	288,815	0.434	0.35
✓	✓	✓	✓	15	20	10	10	131,500	17,354	289,025	0.434	0.33
✓	✓	✓	✓	30	20	10	10	236,500	16,275	384,226	0.577	0.52
✓	✓	✓	✓	30	20	10	20	239,500	16,098	385,626	0.579	0.53

Component	Capital($)+Replacement($)	O&M($)	Fuel($)	Salvage($)	Total($)
PV	105,000	0	0	0	105,000
Diesel Gen	57,795	23,876	69,558	-44	151,185
Converter	6,896	272	0	-3	7,166
Batteries	23,548	0	0	-585	22,964
System	193,239	24,149	69,558	-632	286,315

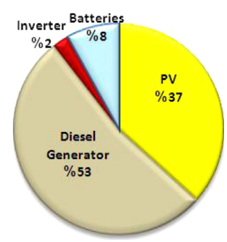

Fig. 7. Cost of PV–diesel–battery power system.

seen from this figure, the high capital cost of PV array has a considerable effect on the total system cost.

In the proposed system, the PV array produces 28,879 kW h electric energy per year, 30% of the total generated electric energy, which is equivalent to 79.1 kW h every day. Table 4 indicates that 65,968 kW h electrical energy, 70% of the total generated electrical energy, is provided annually by the diesel generator. To provide this amount of electrical energy, the generator uses 30,283 L of diesel annually. As is shown in Tables 2 and 4, the total air pollutant emission of this hybrid renewable energy system, with 30% renewable fraction, is 81,894 kg/yr that is 8.5% lower than the emission generated by the discussed stand-alone diesel system.

Since there is no battery storage in the proposed hybrid PV–diesel system, the generated electric power of PV in some periods may be greater than the electric demand. As can be observed from Table 4, the excess electricity production is 20,334 kW h/yr (21.4%).

Application of battery storage in optimization of such hybrid energy systems can presumably result in more economic systems because it makes possible to use the storage of excess electricity from PV later [2]. So, in what follows, the application of the PV–diesel system with battery storage will be analyzed.

5.2. Hybrid PV–diesel–battery system

The optimization results for hybrid PV–diesel system with battery storage are shown in Table 5. The impact of adding battery units to the proposed hybrid system is analyzed by focusing on the scenario highlighted by red ticks in Table 5. This system contains a 15 kW PV array, a 20 kW diesel generator and 10 units of the batteries to cope with about 100 min of autonomy.

Table 5 shows that the total NPC of this hybrid energy system is $286,315. Therefore, coupling the battery units to the prior hybrid system has decreased the total NPC. Although addition of batteries will cause an increase in the total capital and replacement cost, it brings about an annual reduction of $3880 in operating cost. Thus, the total NPC of this system decreases about 7.3% compared to the corresponding system discussed in 5.1; Moreover, the renewable fraction of this proposed system is 35% that is 16.7% higher than the previous no-battery design. Breakdown of the total NPC of this system is shown in Fig. 7.

Since the specifications of PV array (e.g. its capacity and de-rating factor) are the same with the one in Section 5.1, the PV array again produces electrical energy of 28,879 kW h/yr. However, in this case, the part of excess renewable electricity is stored in batteries and will be used when needed, which improves renewable fraction of the proposed system. The reason is that the generated electric power of PV array in this scenario contributes to supplying the electric demand more than the one discussed in Section 5.1. As a result, the need for the diesel generator will be decreased, so the share of non-renewable source in electricity generation will be reduced.

As can be seen from Table 6, the batteries provide electrical energy of 1978 kW h/yr. So, the excess electricity reduces to 7.8%. Considering the fact that the battery bank is only charged by the PV source, the PV array and battery bank supply about 35% of the total generated electrical energy, which is the same with the mentioned renewable fraction of 35%.

One of the considerable results is that the diesel generator operates 6576 h per year and consumes 23,947 L of diesel to provide 53,705 kW h/yr electrical energy, which is 65% of the total generated electrical energy by the proposed system. Comparison of Tables 4 and 6 reveals the lower operation hours of the generator used in this hybrid system with battery bank.

Although the installation of more battery units (i.e. more than 10 units) brings about a higher reduction of excess electricity, it increases the total NPC. For instance, the total NPC for a hybrid PV–diesel (15 kW PV array, 20 kW diesel generator) with 20 batteries is $2500 more than the one related to the proposed system with

Table 6
System components operation results and pollutant emissions for PV–diesel–battery system.

Quantity	Value	Units
Battery		
Energy in	2,319	kW h/yr
Energy out	1,978	kW h/yr
Losses	335	kW h/yr
Annual throughput	2,145	kW h/yr
Expected life	5.01	yr
Diesel generator		
Hours of operation	6,576	h/yr
Number of starts	643	starts/yr
Operational life	2.28	yr
Marginal generation cost	0.0800	$/kW h
Electrical production	53,705	kW h/yr
Mean electrical output	8.17	kW
Max. electrical output	17.9	kW
Fuel consumption	23,947	L/yr
Pollutant		
Carbon dioxide	63,061	kg/yr
Carbon monoxide	156	kg/yr
Unburned hydrocarbons	17.2	kg/yr
Particulate matter	11.7	kg/yr
Sulfur dioxide	127	kg/yr
Nitrogen oxides	1,389	kg/yr

10 units of battery although the excess electricity reduces to 6.32%. Therefore, with a considerably large percent increase in the total NPC, adding 10 more battery units does not seem to be cost-effective as it will only have a negligibly small effect on the excess energy and renewable fraction of the proposed system.

Finally, it should be noted that the application of batteries has reduced the gas emissions of the proposed system significantly because of the reduction in operation hours of the diesel generator. As can be observed from Table 6, the total air pollutant emission of the proposed hybrid renewable energy system with 10 batteries is 64,762 kg/yr that is 27.6% less than the one related to the system without battery.

6. Conclusion

In this study, a hybrid renewable energy system based on photovoltaic and diesel generators with battery storage capacity is suggested. The software HOMER is used for the simulation purposes. In this study, the main concentration is on the net present cost, renewable fraction and air pollutant emission as the criteria determining the most viable systems. The results indicate that the stand-alone hybrid renewable energy system composed of 15 kW PV array, a 20 kW diesel generator and a 20 kW inverter can supply 200 kW h/d energy consumption with a peak demand of 18 kW of the case study location. The NPC of the system is $309,034 during projection period of 25 years and 10% annual real interest rate. The renewable fraction varies between zero and 30%.

Further, the effect of penetration of battery storage on renewable fraction and NPC is investigated. Addition of 10 units of battery to the proposed system reduces the total net present cost to $286,315 and increases the renewable fraction to 35%.

Therefore, considering the potential of solar radiation and existence of remote villages in Khorasan-E-Jonoobi province of Iran, which are far from utility grid, stand-alone hybrid PV–diesel–battery energy systems are not only perfectly viable but also compellingly apposite candidates for electrification of these villages.

References

[1] Silva SB, Oliveira MAG, Severino MM. Economic evaluation and optimization of a photovoltaic–fuel cell–batteries hybrid system for use in the Brazilian Amazon. Energy Policy 2010;38(11):6713–23.
[2] Lau KY, Yousof MFM, Arshad SNM, Anwari M, Yatim AHM. Performance analysis of hybrid photovoltaic/diesel energy system under Malaysian conditions. Energy 2010;35(8):3245–55.
[3] http://www.eecm.ir.
[4] 〈www.krec.ir〉.
[5] 〈news.tavanir.org.ir〉.
[6] 〈www.nrel.gov/homer〉.
[7] Bernal-Agustín JL, Dufo-López R. Simulation and optimization of stand-alone hybrid renewable energy systems. Renewable and Sustainable Energy Reviews 2009;13(8):2111–8.
[8] Asrari A, Ghasemi A, Javidi MH. Economic evaluation of hybrid renewable energy systems for rural electrification in Iran—a case study. Renewable and Sustainable Energy Reviews 2012;16(5):3123–30.
[9] Al-Karaghouli A, Kazmerski LL. Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software. Solar Energy 2010;84(4):710–4.
[10] Connolly D, Lund H, Mathiesen BV, Leahy M. Review of computer tools for analysing the integration of renewable energy into various energy systems. Applied Energy 2010;87(4):1059–82.
[11] Farret FA, Simões MG. Integration of alternative sources of energy. New York: John-Interscience; 2006.
[12] Demiroren A, Yilmaz U. Analysis of change in electric energy cost with using renewable energy Sources in Gökceada Turkey: an island example. Renewable and Sustainable Energy Reviews 2010;14(1):323–33.
[13] 〈www.meteonorm.com〉.
[14] NASA surface meteorology and solar energy; 2004. Available: 〈http://eosweb.larc.nasa.gov/sse/〉.
[15] Nfah EM, Ngumdam JM, Tchinda R. Modelling of solar/diesel/battery hybrid power systems for far-north Cameroon. Renewable Energy 2007;32(5):832–44.
[16] 〈http://www.iraneconomist.com〉.
[17] Khan MJ, Iqbal MT. Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland. Renewable Energy 2005;30(6):835–54.
[18] Shaahid SM, El-Amin I. Techno-economic evaluation of off-grid hybrid photovoltaic–diesel–battery power systems for rural electrification in Saudi Arabia–a way forward for sustainable development. Renewable and Sustainable Energy Reviews 2009;13(3):625–33.